Recursivity as a pedagogical foundation: An integrative model from biology, cognition, and social mediation

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Abstract

Education has historically privileged linear models of knowledge transmission, ignoring that deep learning, creativity, and ecological consciousness emerge from a universal pattern: recursivity—understood as a system's capacity to fold back upon itself to generate novelty. This article integrates evidence from evolutionary biology (Margulis's endosymbiosis, Goodwin's self-organization, Ho's organic coherence), animal cognition (Balcombe and De Waal's empathy), developmental psychology (Vygotsky's Zone of Proximal Development, Bateson's learning levels), and philosophy of mind (Brentano's intentionality, Corballis's mental time travel and theory of mind), to propose that recursivity is the architectural principle of life and mind. From this synthesis, a pedagogy of the recursive loop is formulated, organized in five phases—intentional engagement, exploratory mediation, sudden reorganization (insight), socio-affective internalization, and ecological expansion—that transforms the classroom into a workshop of recursive consciousness. It is concluded that educating is, in essence, facilitating the learner to unfold the same folding pattern that has constructed biological complexity and animal empathy, leading them toward an ever-deeper understanding of themselves, others, and the system that sustains them.

Keywords: recursivity, pedagogy, Zone of Proximal Development, intentionality, endosymbiosis, empathy, self-organization, transformative learning.

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1. Introduction

For decades, education has been conceived as a linear process: a sender deposits information into a receiver, who accumulates it sequentially. However, the everyday experience of learning reveals phenomena that overflow this scheme: the sudden spark of comprehension, the capacity to place oneself in another's position, the sensation that new knowledge reorganizes everything we knew. These experiences share a deep structure: they are recursive. The mind does not limit itself to adding data but turns back upon its own contents, reconfigures them, nests them, and generates an emergent level of understanding.

The present article argues that recursivity is not a technique nor a philosophical curiosity, but the very foundation of all genuine learning. To demonstrate this, a bridge is woven between disciplines that rarely dialogue: the biology of endosymbiosis, the ethology of animal empathy, developmental cognitive psychology, and the philosophy of intentionality. The objective is to construct a coherent pedagogical model, based on evidence that life, mind, and culture unfold through loops that fold back upon themselves. Education can become the deliberate facilitation of these folds.

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2. Recursivity as a Universal Principle: An Interdisciplinary Journey

2.1 The biological loop: endosymbiosis, self-organization, and coherence

Lynn Margulis (1967) revolutionized biology by demonstrating that the eukaryotic cell did not emerge through gradual mutations but through endosymbiosis: an archaea phagocytized an aerobic bacterium that became a mitochondrion; another cyanobacterium was incorporated as a chloroplast. This act of internalization is a biological recursivity: one organism folds another within itself, and from this fusion emerges a unit of superior complexity. Life does not advance in a straight line; it nests.

Brian Goodwin (1994) deepened this idea by studying morphogenesis. For him, an organism's form is not dictated by a rigid genetic program but by loops of local interaction between cells. Each cell communicates with its neighbors, inhibiting or activating genes, and from this recursive dance of signals, global patterns emerge (the stripes of a shell, the symmetry of a flower). It is the loop global form – local interaction that generates biological order.

Mae-Wan Ho (1993) took this vision even further: the organism is a liquid-crystalline medium in quantum coherence, where each part resonates with the whole. A local perturbation propagates instantaneously through the system, and the regenerative response involves the entire organism. It is a fractal fold: organism – cell – organism. Here, recursivity is not temporal but simultaneous: each point contains the information of the whole.

Gregory Bateson (1972), a biologist and cybernetician, had already intuited that "mind" does not reside inside the skull but is an information circuit that includes the organism and its environment. His "Ecology of Mind" describes nature as a network of feedback loops. Human pathology, he said, arises when consciousness arbitrarily cuts a fragment from the loop and forgets that it itself is part of the circuit. Biological recursivity is, therefore, the substrate of all possible cognition.

2.2 The animal loop: empathy, sudden perception, and proto-intentionality

Contemporary ethology has demolished the wall that separated humans from the rest of the animal world regarding mental life. Frans de Waal (2009) and Jonathan Balcombe (2016) have documented that empathy—emotional contagion and the capacity to console—is widespread among mammals, birds, and even fish. A mouse becomes stressed upon seeing a fellow creature suffer; a bonobo embraces a defeated individual.

This basic empathy can be described as an emotional recursive loop: I feel the other's pain. One's own pain experience folds over the perception of another's pain, generating a caring response. De Waal demonstrates that great apes go further: they possess "cognitive empathy," an incipient capacity to take the other's perspective. It is the evolutionary precursor of human theory of mind.

Meanwhile, Gestalt psychology (Köhler, 1921; Wertheimer, 1945) showed that learning is not always associative and linear. Köhler's chimpanzees solved problems through insight: after a period of apparent blockage, the perceptual field suddenly reorganized and the solution appeared. Insight is an instantaneous cognitive feedback loop: the desired end projects onto the available means, reconfiguring the perception of parts in function of the whole. It is an act of perceptual recursivity: seeing the relationship of parts from the whole.

Both phenomena—empathy and insight—show that recursivity is not a philosophical luxury but a basic strategy of animal intelligence for navigating

the social and physical world. Human pedagogy can learn much from these evolutionary masters.

2.3 The human loop: intentionality, mediation, and recursive consciousness

Franz Brentano's philosophy (1874) identified intentionality as the distinctive trait of the mental: every psychic act is directed toward an object. Thinking is thinking of something; desiring is desiring something. This intentional arrow is the raw material of consciousness, but in the infant it is direct and unreflective. How does it become the adult capacity to reflect upon one's own thoughts? Lev Vygotsky (1934) offered the answer: through the Zone of Proximal Development (ZPD). Every higher mental function first appears on the social plane and is then internalized. The adult not only helps the child perform a task; they lend them their own recursivity. When a mother asks, "Do you remember what happened yesterday?" she is modeling the structure of episodic memory. When she says, "How do you think he felt?" she is scaffolding theory of mind. The ZPD is the social workshop where the child's intentionality is taken, folded back upon itself by the mediator, and returned in the form of a question or dialogue. The child internalizes this dialogue as "private speech" and, finally, as reflective thought.

Michael Corballis (2011) described the two great recursive capacities that emerge from this process: mental time travel (simulating the self in the past or future) and nested theory of mind (inserting mental states within others: "I believe that you believe that I want..."). Both are, in essence, the capacity to fold intentionality: applying the thinking function to its own products. Corballis argues that this recursivity is what made syntactic language, cumulative culture, and autobiographical consciousness possible.

Bateson (1972) formalized these folding levels with his theory of learning levels:

• Learning I: change in response within a fixed context (conditioning).

• Learning II (Deutero-learning): change in the learning process itself; "learning to learn"; character formation.

• Learning III: change in the premises of deutero-learning; profound questioning of one's own worldview.

Learning III is recursivity applied to the very loop that constitutes us. It is the possibility of freeing ourselves from automatisms and seeing our own patterns as objects of reflection.

2.4 Synthesis: recursivity as a connecting pattern

Biology, animal cognition, and human development show the same architecture of folds. Life becomes complex by nesting systems (Margulis). The organism is formed through recursive dialogues between parts and the whole (Goodwin, Ho). Animal empathy is a loop of shared feeling (De Waal, Balcombe). Meaningful learning is a sudden reorganization of the field (Gestalt). Human consciousness emerges when intentionality is socially mediated to turn back upon itself (Brentano, Vygotsky, Corballis). And maturity consists of learning to learn about one's own learning (Bateson).

Pedagogy, if it wants to be faithful to the nature of mind and life, must assume recursivity not as one more content but as the organizing principle of all its practice.

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3. Toward a Pedagogy of the Recursive Loop

3.1 Pedagogical principles derived from interdisciplinary evidence

1. **Principle of intentional nesting:** Always start from the learner's living intentionality (Brentano). The desire to know, curiosity, emotion are the energy of the loop. The teacher should not ignore them but welcome and redirect them.
2. **Principle of recursive mediation:** Learning occurs in the ZPD when the mediator lends their capacity to fold the student's attention back upon their own processes (Vygotsky). Questions are the tool: "How did you arrive at that?", "What would happen if...?", "How would another person see it?"
3. **Principle of sudden reorganization (insight):** Create conditions for the learner to reconfigure their perceptual or conceptual field. Not everything is sequential; silence, contemplation, and the presentation of paradoxes facilitate the qualitative leap (Gestalt).
4. **Principle of empathy and social recursivity:** Systematically include perspective-taking. Understanding deepens when the student can simulate the point of view of a peer, a historical figure, or a non-human living being (De Waal, Corballis).
5. **Principle of ecological expansion of the loop:** Help the student see themselves as part of broader systems. Learning does not end with the

"I"; it must include the social loop and the environmental loop, recognizing the feedbacks that connect us to community and to the Earth (Bateson, Ho).

3.2 Methodology: The Recursive Inquiry Cycle (RIC)

A five-phase methodology is proposed that operationalizes these principles. It is not a rigid sequence but a flexible loop that can be iterated at different scales (a session, a teaching unit, an annual project).

Phase 1. Intentional Engagement

A phenomenon, image, dilemma, or story is presented that connects with the student's experience and curiosity. They are invited to express what catches their attention, what they feel, what questions arise. The teacher collects and validates these primary intentionalities. (Foundation: Brentano, Balcombe — emotion as the gateway).

Phase 2. Exploratory Mediation

The teacher introduces questions that fold the student's attention toward their own processes or toward others' perspectives. Examples: "What did you notice first and why?", "If you were the protagonist, how would you feel?", "What do you think your classmate was thinking when they said that?" Dialogue in pairs or groups is encouraged. (Foundation: Vygotsky, ZPD; De Waal, basic theory of mind).

Phase 3. Sudden Reorganization (Insight Loop)

Space is created for non-linear synthesis. This can be a moment of silence, a paradoxical question ("Is it possible that both opinions are true at the same time?"), or the requirement to express what has been learned in a new format (drawing, metaphor, dramatization). The goal is to facilitate the student restructuring their understanding, not accumulating more data. (Foundation: Gestalt, insight; Bateson, Learning II).

Phase 4. Socio-Affective Internalization

Scaffolding is progressively withdrawn. Students are asked to generate their own recursive questions, write an internal dialogue, or teach a classmate what they have understood. Self-assessment and peer assessment based on criteria of empathy and reflective depth consolidate recursivity as a habit. (Foundation: Vygotsky, internalization; Corballis, mental travel and self-narrative).

Phase 5. Ecological Expansion of the Loop

Learning is connected to a broader system. Questions like: "What consequences does this have for our community?", "If the forest could speak, what would it say about our decision?", "How will this affect future generations?" The aim is to fold consciousness to include social and environmental feedback loops. (Foundation: Bateson, ecology of mind; Ho, organismic coherence; Margulis, symbiosis as metaphor for interdependence).

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4. Implications for Teacher Training and Evaluation

For this pedagogy to be viable, the teacher must be trained as a recursive mediator. It is not enough to know the content; they must master the art of the folding question, the silence that reorganizes, and the listening that validates the student's intentionality. Teacher training should include experiential practice in self-observation, empathy, and systemic thinking.

Evaluation, for its part, cannot be reduced to closed-response tests. Instruments that capture the quality of the recursive loop are required: metacognition rubrics, reflection portfolios, observation of empathic dialogue, and projects that demonstrate systemic understanding. The question is not only "what do you know?" but "how did you come to know it?", "from what other perspectives could you look at it?" and "what implications does it have for the world?"

Comparative Table: Linear vs. Recursive Model (Pedagogical Implications)

Dimension	Linear Model (Traditional)	Recursive Model (Proposed)
Conception of learning	Sequential accumulation of data	Folding and reorganization of experience
Teacher's role	Transmitter of information	Mediator of questions that fold attention

Dimension	Linear Model (Traditional)	Recursive Model (Proposed)
Student's role	Passive receiver	Active agent of their own reflective loop
Pedagogical time	Sequential, rigid, chronological	Cyclical, flexible, based on moments of insight
Evaluation	Closed response, memorization	Metacognition rubrics, reflective portfolios
Biological foundation	Mechanism / Instruction	Endosymbiosis / Self-organization
Final objective	Learn content	Learn to learn and to be part of the system

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5. Conclusion

Recursivity is not an invention of modern pedagogy nor an unnecessary sophistication. It is the pattern with which life has woven complexity since the first bacterium that welcomed another within itself, with which animals feel another's pain and reorganize their perception, and with which human beings construct our identity and our culture. Educating is, in its deepest sense, facilitating each new generation to become aware of that loop and learn to dance with it.

A pedagogy founded on recursivity not only improves performance, creativity, and skill; it cultivates empathy, self-regulation, and ecological consciousness. It turns the classroom into a microcosm of the living mind, where intentionality folds, encounters that of others, and expands to embrace the world. Faced with today's civilizational challenges—polarization, environmental crisis, loss of meaning—recursive education is not an additional option: it is an evolutionary necessity. The good news is that the loop is already there, waiting to be awakened.

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